Fossil Mollusca from the Samburu Hills, Northern Kenya

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ABSTRACT Fossil molluscs are important indicators of past environmental conditions. 12 taxa of mollusca belonging to the period from Miocene to Holocene were collected mainly at the Samburu Hills in the north-central Kenya. The terrestrial snail fauna of the Kongia Formation is comparable with that from modern woodland to forest.

INTRODUCTION

Miocene to Recent sediments and volcanics are extensively exposed in the Samburu Hills (Baker, 1963) between Nachola in the east and the Suguta Valley in the west. Mollusca are generally poorly represented in the local fossil record except for isolated rich occurrences in Miocene and Holocene strata. The exposures of Middle Miocene sediments at Nachola have not so far yielded a single specimen, and the extensive upper Miocene deposits in the region of Namurungule and Nakaporatelado Luggas have yielded only one minor assemblage of *Melanoides*, despite many square kilometres of exposures of lacustrine and fluvio-lacustrine sediments.

The most interesting fossil molluscs come from an area of sediments intercalated in lavas at Kongia, seven kilometres north of Namurungule cliffs on a track which leads eventually to the Suguta Valley. A rich but less intriguing set of assemblages comes from Holocene strata (grey silts) which are thought to be equivalent to the Galana Boi Silts which are widely developed in the Turkana Basin north of the Barrier.

THE MOLLUSCAN ASSEMBLAGES

Aka Aiteputh Formation; Locality SH 17

The oldest mollusc assemblage so far collected from the Samburu Hills is from Locality 17 between Namurungule and Nakaporatelado Luggas (Pickford *et al.,* 1984). It occurs at the base of the sedimentary sequence, in clays and silts below the siliceous limestone member of the Aka Aiteputh Formation. Twenty six snails, all coated in algal limestone were collected at this locality, but many more were left in the field. In a few specimens, for example SH-929'82 and SH-923'82, part of the limestone coating has broken cleanly away from the shell, revealing well preserved surface sculpture typical of *Melanoides tuberculata*. Judging from the shape of the specimens, they are probably all referable to the same species.

Fossil molluscs are unknown from the overlying Namurungule Formation, which outcrops extensively in the Samburu Hills.

Kongia Formation; Localities SH 47 and SH 48

Abundant upper Miocene Mollusca have been found at localities SH 47 and SH 48, seven kilometres north of the main outcrops of the Namurungule Formation. Although the area has not been mapped in detail, it is considered likely that the sequence is younger than that exposed at Namurungule, and that it is of Upper Miocene to Pliocene age.

Sediments at these localities are usually less than a metre thick, and represent thin intercalations of pink marl between flows of basaltic lava. An unusual feature of the fauna is that both terretrial and aquatic molluscs occur in the strata, although they are not intimately mixed together, usually occurring in discrete (terrestrial or aquatic) faunules. Algal stromatolites are a common feature of the strata, but vertebrates are rare, only *Hippopotamus*, fish and *Varanus* having been seen. Insect cocoons occur in the marls.

The terrestrial snail fauna is of particular interest since it yields evidence concerning past environments in the area. Terrestrial taxa so far identified include *Burtoa nilotica, Limicolaria* aff. *martensiana, Trochonanina (Bloyetia)* aff. *nyiroensis, Chlamydarion hians,* and *Tropidophora (Ligatella) anceps.* The environmental indications of such a fauna are comparable with those from modern woodland to forest at altitudes intermediate between extant "Nyika" and the Kenya Highlands (ca. 1300–1400 metres). The closest modern analogues to be found are the snail faunas on the margins of the "island" forests of the Ndoto Hills and Marsabit, in Kenya. In the Upper Miocene, the area was certainly considerably wetter and more vegetated than it now is. The modern snail fauna from Samburu, which is a hot semi-desert, consists of *Pupoides caenopictus, Gastrocopta, Zootecus, Truncatellina* and other taxa characteristic of semi-desert areas.

The aquatic mollusc fauna from the Kongia Formation is somewhat restricted, but is typically lacustrine, containing abundant *Cleopatra* aff. *africana* and *Melanoides tuberculata* (2 varieties) with fewer *Mutela* sp. The lake in which these molluscs lived was presumably freshwater.

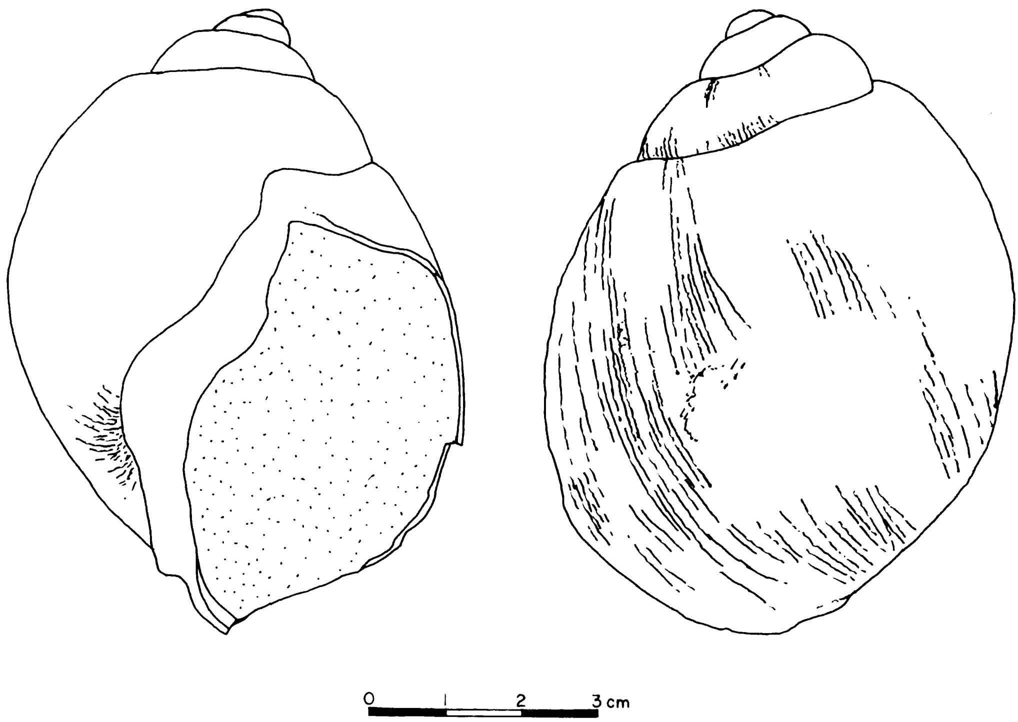

Fig. 1. Terrestrial snails from the Locality SH 47. *Burtoa nilotica*

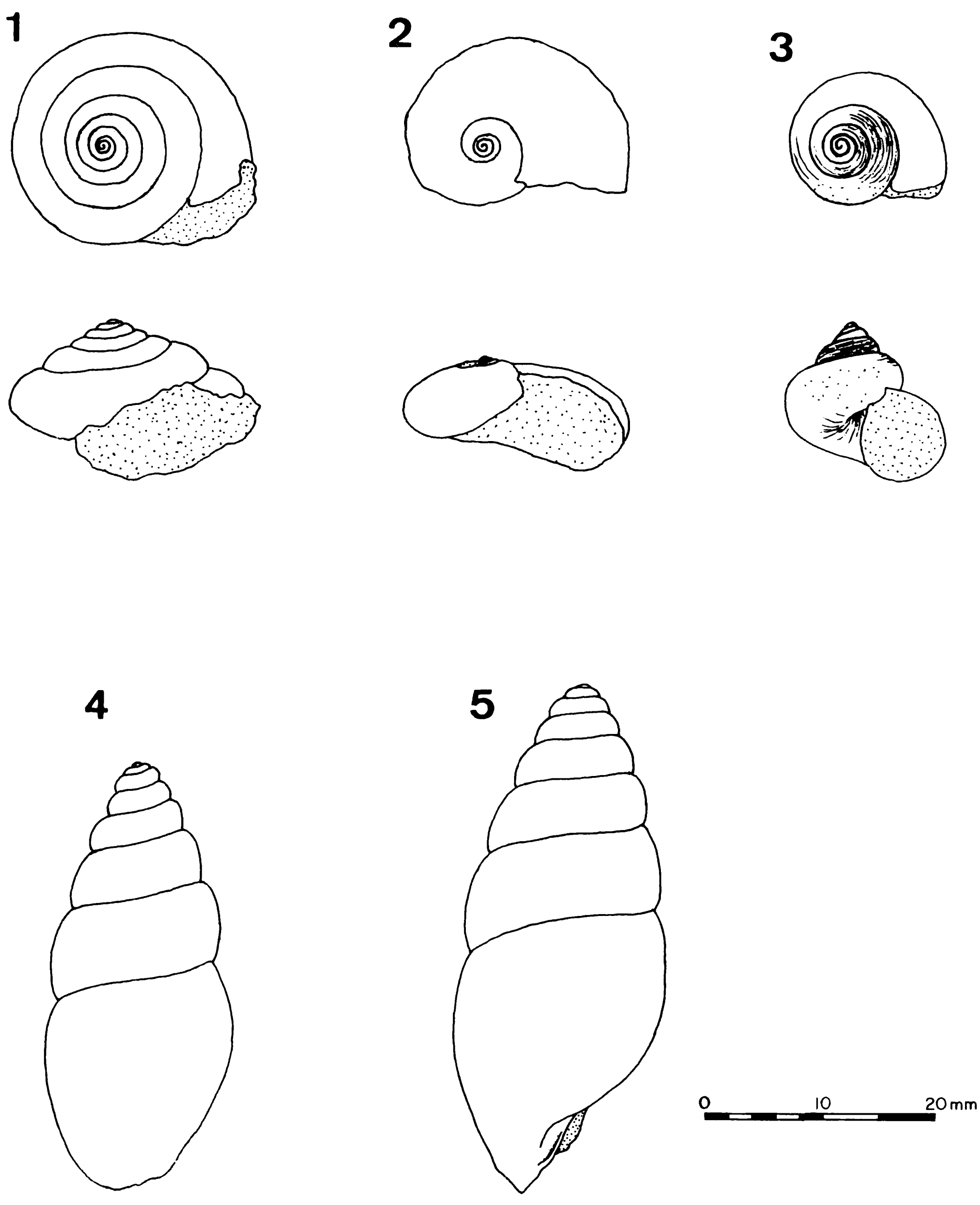

Fig. 2. Terrestrial snails from the Locality SH 47.
1. *Trochonanina (Bloyetia)* aff. *nyiroensis* 2. *Chlamydarion* aff. *hians*
3. *Tropidophora (Ligatella)* aff. *anceps* 4. *Limicolaria* aff. *martensiana*
5. *Limicolaria* aff. *martensiana* slightly crushed specimen

Holocene Molluscs of the Grey.Silts (Localities GB 1-10)

In many places in the Samburu Hills, patches of grey lacustrine silts are exposed in terraces and valley deposits up to an altitude of 620 metres above sea level which is 370 metres above the present floor of the Suguta Valley in the region of Lake Logippi, (Baker, 1963). Fossil molluscs and fish are commonly preserved in these grey silts, which are of latest Pleistocene or Holocene age (Truckle, P.H., 1976).

Travertine deposits in the sequence suggest that the area was fed by water seepages which deposited limestone in their proximity. It seems likely that the sediments at Naturkon accumulated at about the same time that "Lake Suguta" was at its maximum depth.

Holocene Mollusca from the Baragoi Silts

In the Baragoi Silts, which outcrop as fluvial terrace deposits immediately west of Baragoi township, occurs a terrestrial mollusc fauna which differs markedly from modern snail faunas of the area. In particular, the species *Chlamydarion hians* is common, yet today it only occurs at much higher altitudes in the Ndotos, the Mathews Range and equally elevated areas. Since the distribution of *Chlamydarion* is related to humidity and temperature, it is more than likely that the climate at Baragoi, at the time of accumulation of the Baragoi Silts, was considerably more humid and colder than it now is. The degree of fossilisation of material (which is actually subfossil) indicates that any such climatic change was probably quite recent, possibly late in the Holocene.

The grey silts possibly equate with the Galana Boi Silts which are exposed extensively to the East of Lake Turkana, and it is possible that the two units accumulated in a single lake basin prior to the formation of the "Barrier" which dissected proto-lake Turkana into two portions (Champion, 1935). The southern (Suguta) portion subsequently became starved of input waters, and virtually dried up (only seasonal Lake Logippi remains). Truckle (1976), considered however, that the Barrier played a subsidiary role in the subdivision of an enlarged Lake Turkana, and that a climatic change was the dominating factor in the dessication of the Suguta Trough. The highest terraces in the Samburu Hills indicate a former maximum depth of "Lake Suguta" of about 370 metres.

Molluscs so far identified from the grey silts are as follows (Table 1):

Bivalvia	Mutelidae (? *Mutela*)
	Caelatura sp.
	Corbicula africana
Gastropoda	*Melanoides tuberculata*
	Biomphalaria sp.

At Naturkon, (loc. GB 10) a fluvial terrace deposit is preserved which yields abundant snails of paludal affinities including.

Lymnaea sp.
Bulinus (Physopsis) sp.
Melanoides tuberculata (2 varieties)

TAXON \ SITE	GB 1	2	3	4	5	6	7	8	9	10
Mutela	●									
Caelatura	●									
Corbicula	●		●							
Melanoides	●	●	●	●	●	●	●	●	●	●
Biomphalaria						●		●		●
Lymnaea										●
Bulinus(Physopsis)										●

Table 1. Distribution of molluscs from GB sites (grey silts)

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VOLCANIC ROCKS IN THE SAMBURU HILLS, NORTHERN KENYA

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ABSTRACT Volcanic rocks of the Samburu Hills are composed mainly of basaltic lava flows (ankaramite, olivine basalt and hawaiite) intercalated with differentiated rock lava flows and welded tuffs (trachyte and alkali rhyolite).

Basaltic rocks of various ages, from Miocene to Recent, were collected from an area of 10 x 10 km^2 (Suguta Area) and their petrography and petrochemistry are described. A decrease in degree of silica-undersaturation with time from alkali basalts to transitional basalts can be recognized. Successive decrease in depth of segregation of primary magmas can explain the temporal variation in chemical composition.

INTRODUCTION

The East African Rift is characterized by profuse volcanism with a total volume of ejecta of 500,000 km^3 (Baker *et al.* 1972). Petrologic study of the volcanic rocks would, therefore, provide essential information about the evolution of the rift. Based on the compilation of numerous geochronological and petrochemical data (Harris, 1969; Williams, 1972; Lippard and Truckle, 1978; Baker *et al.*, 1978; Barberi *et al.*, 1982), the chemical variation of the volcanic rocks in both time and space can be roughly summarized as follows;

– a decrease in alkalinity and degree of silica-undersaturation occurs 1) with time as well as 2) across the rift towards the axis and 3) along the rift northward. However these trends are still so rough and qualitative that we cannot understand their geologic implications with respect to structural geological and geophysical data. More detailed data concerning the chemical variation are required.

The purpose of this paper is to examine the temporal variation in basalt chemistry in the rift near Samburu and to understand the evolution of the rift based on recent experimental studies on the magma genesis (e.g. Jaques and Green, 1979, 1980; Takahashi *et al.*, 1981; Takahashi and Kushiro, 1983).

New petrochemical and petrographical data concerning the volcanic rocks from the Samburu Hills, Kenya, where a sequence of Miocene, Plio-Pleistocene and Recent basalts was established during the 1982 Japan/Kenya expedition, will be described. In order to eliminate the effect of spatial variation and to determine the temporal variation in chemistry, the sites from which the samples were collected were confined to a small area of 10 x 10 km^2. Petrologic investigations were mainly carried out on relatively magnesian basalts.

FIELD OCCURRENCES

The investigated area is situated on the eastern flank of the Suguta Valley, 50 km to the south of Lake Turkana and 30 km west of Baragoi. Preliminary surveys were done around Nachola Village and to the northwest of Baragoi. The former area is called Suguta Area, the latter Baragoi Area (Fig. 1). Volcanic rocks in both areas are composed mainly of basaltic lava flows intercalated with lava flows and welded tuffs of more differentiated rock, such as trachyte and alkali rhyolite. The detailed geology and stratigraphy of these areas are given by Makinouchi *et al.* (1984).

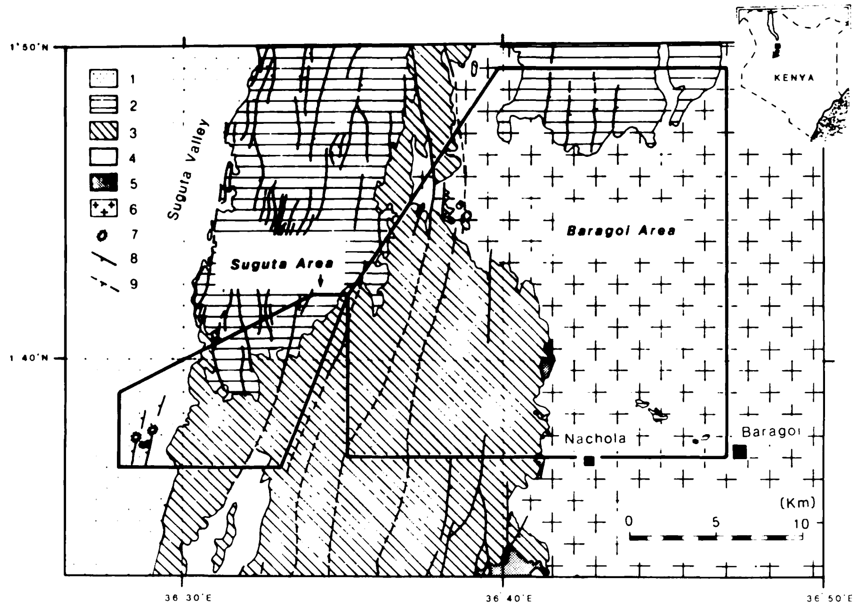

Fig. 1: Index map showing positions of the "Suguta Area" and the "Baragoi Area". Based on Baker's geological map (1963), which is simplified and slightly modified. 1; Superficial deposits. 2; Volcanic rocks of the Tirr Tirr Formation. 3; Volcanic rocks of the Nagubarat, Kongia, Aka Aiteputh and Nachola Formations. 4; Sedimentary rocks of the Namurungule Formation. 5; Sedimentary rocks of the Nachola Formation. 6; Basement rocks (Pre-Cambrian). 7; Scoria cones. 8; Faults, observed. 9; Faults, inferred.

The volcanic rocks of the Suguta Area are divided into five formations separated from each other by unconformities. From lower to upper these are the Aka Aiteputh Formation, the Namurungule Formation, the Kongia Formation, the Nagubarat Formation and the Tirr Tirr Formation.

The Aka Aiteputh Formation is mainly composed of basaltic rocks (including some ankaramites and hawaiites) which are rarely interstratified with trachytic lava flows and welded tuffs. The K-Ar age of the uppermost lava of this formation is 12 Ma (Matsuda *et al.*, 1984). The Namurungule Formation is composed of sedimentary rocks, including mud flow deposits and lake deposits. The Kongia Formation is composed of basaltic rocks. The K-Ar age of the lowermost lava of this formation is 6 Ma (Matsuda *et al.*, 1984). Strata in these three formations generally dip several tens of degrees westwards.

Alkali basalt lava flows and necks, which unconformably overlie the Aka Aiteputh, Namurungule and Kongia Formations and dip westwards at about ten degrees, belong to the Nagubarat Formation.

Nearly horizontal basalt and alkali rhyolite lava flows, which unconformably overlie the Aka Aiteputh and Kongia Formations belong to the Tirr Tirr Formation. This formation was called the "Tirr Tirr series" by Baker (1963). The K-Ar age of the alkali rhyolite of this formation is about 4 Ma (Baker *et al.*, 1971).

Besides the above five formations several scoria cones with or without lava flows form alignments along normal faults in the Sugura Valley. The scoria cones preserve their original topography very well (Plate 1, Fig. 1) and are considered to be of Recent Age.

In the Aka Aiteputh Formation samples were collected from several horizons. Stratigraphic relationships among most of the horizons are clear, although for the uppermost part of this formation two samples may have been collected from the same horizons, because two routes were used when the rocks were collected. In the Kongia Formation samples were collected from many horizons along a route where the stratigraphic relationships are clear. Samples were collected from two lava flows in the Nagubarat Formation, but the stratigraphic relationship between the two flows is not clear at present. In the Tirr Tirr Formation samples were collected from many stratigraphic horizons. Only one basalt sample was collected from a scoria cone in the Suguta Valley. Thus volcanic rocks of various ages, from Miocene to Recent, were collected from the Suguta Area.

In the Baragoi Area occur the Nachola Formation and younger unnamed basaltic lava flows of unknown sequence. The Nachola Formation consists of alternations of volcanic rocks and sedimentary deposits. Strata of this formation dip several tens of degrees westwards. This formation is presumed to correlate with or to underlie the Aka Aiteputh Formation. The younger basaltic lava flows unconformably overlie the Pre-Cambrian Basement and/or the Nachola Formation. They are nearly horizontal and may correlate to the Tirr Tirr Formation. Samples were randomly collected in this area.

In this paper volcanic activity of the Suguta Area is divided into four stages separated from each others by major clino-unconformities. Stage I corresponds to the Aka Aiteputh and Kongia Formations. This stage is subdivided into two substages corresponding to the two formations. Stage II to IV corresponds to the Nagubarat and Tirr Tirr Formations and the volcanics in the Suguta Valley, respectively.

ANALYTICAL METHODS

Most of the whole rock analyses (10 oxides) were done with the Rigaku XRF of the University of Tokyo. Details of the analytical method were reported by Matsumoto and Urabe (1980). Chemical compositions of minerals were determined by electron probe microanalyzer model JEOL JXA-5 of the Geological Institute and JEOL JCXA-733 of the Ocean Research Institute of the University of Tokyo. The analytical procedure is similar to that given by Nakamura and Kushiro (1970), and the correction procedure of Bence and Albee (1969) was followed.

PETROGRAPHY

(1) Basaltic rocks

Description of representative samples

Basaltic rocks occur as lava flows or sills all over the district. Only lava flows will be considered in this paper. Basaltic rocks can be divided into three types based on their petrographic features as follows;

(i) Ankaramite (Aka Aiteputh and Kongia Formations)
(ii) Olivine basalt (all the formations)
(iii) Hawaiite (Aka Aiteputh, Kongia and Tirr Tirr Formations)

The six samples on which K-Ar age determinations were carried out (82101504, 82101501, 82082401, 82100106, 82100113 and 82100114) are also described below.

(i) Ankaramite

Basaltic rocks characterized by abundant olivine and clinopyroxene phenocrysts (more than 20 vol.%) are named ankaramite in this paper. Most of them have normative nepheline, but ankaramites in the Kongia Formation (e.g. 82083106) have normative hypersthene.

Table 1

Modal analyses of basaltic rocks in the Suguta Area.

Sample No.	ol	cpx	pl	mt	gm
82083101	0.6	0.2	1.1	0.0	98.1
N-32	4.0	1.6	0.0	0.0	94.4
82082501	0.6	0.1	0.6	tr	98.7
82100407	0.0	0.0	0.0	0.0	100.0
82100406	0.9	1.1	10.3	0.0	87.3
82100403	0.1	0.0	1.0	0.0	98.9
82083104	21.0	9.2	0.0	0.0	69.8
82083106	11.1	10.4	0.0	0.0	78.5
82083107	0.0	0.0	0.0	0.0	100.0
82083108	0.0	0.0	0.0	0.0	100.0
82083109	0.5	0.0	2.2	0.0	97.3
82083110	3.7	1.3	9.8	0.0	85.2
82100103	1.5	1.5	0.0	tr	97.1
82100104	0.0	0.0	0.0	0.0	100.0
82100105	0.8	0.0	1.5	0.0	97.7
82100106	0.6	0.0	0.9	0.0	98.5
82100110	3.9	7.9	0.0	0.0	88.2
82100113	3.5	2.6	0.1	0.1	93.7
82100114	1.0	2.5	21.2	0.2	75.3
82092801	0.9	tr	0.0	0.0	99.1
82092803	0.6	0.0	0.1	0.0	99.3
82092804	6.7	4.8	0.2	0.0	88.3
82092806	0.0	0.0	0.0	0.0	100.0
82092812	2.1	5.7	0.7	0.0	91.5
82092814	6.4	1.7	0.0	tr	91.9
82092817	12.3	29.3	0.0	0.0	58.4
82092818	0.8	5.1	1.4	0.1	92.6
82093001	10.5	14.5	0.0	tr	75.0
82100903	2.3	9.6	0.0	0.0	88.1

ol: olivine cpx: clinopyroxene pl: plagioclase mt: magnetite gm: groundmass
Sequence is the same as Fig. 8.

82093001 (Aka Aiteputh Formation): This rock is one of the most silica-undersaturated basaltic rocks in the Samburu District (15 wt% normative nepheline). It contains euhedral to subhedral olivine and augite phenocrysts. The total amount of phenocrysts is 25 vol.% (Table 1). These phenocrysts contain inclusions of euhedral chromian spinel. Microphenocrysts are olivine, augite and an opaque mineral. The augite microphenocrysts show conspicuous hourglass structure. Olivine is partly replaced by serpentine, especially along cleavage planes. Groundmass shows intergranular to intersertal texture. It is composed of lath-shaped plagioclase, euhedral titanaugite, olivine and opaque minerals with interstitial alkali feldspar, zeolite, nepheline and a green clay mineral. The clay mineral is considered to be altered glass. Zeolite also occurs filling a druse.

Table 2

Chemical compositions of phenocrystic minerals

	FELDSPAR				OLIVINE	
	1	2	3		4	5
SiO_2	51.94	53.09	67.33		39.31	29.97
TiO_2	0.15	0.16	0.00		0.01	0.01
Al_2O_3	29.12	29.12	18.20		0.00	0.01
FeO	0.61	0.54	0.79		8.83	65.92
MnO	0.00	0.00	0.03		0.47	2.95
MgO	0.17	0.13	0.00		49.87	0.09
CaO	13.11	12.54	0.01		0.15	0.37
Na_2O	4.01	4.38	7.55		0.00	0.00
K_2O	0.23	0.26	6.20		0.00	0.00
NiO	0.00	0.00	0.01		0.19	0.00
Cr_2O_3	0.01	0.01	0.03		0.05	0.00
V_2O_3	0.00	0.01	0.00		0.00	0.01
total	99.35	100.23	100.13		99.28	99.35
	O = 8	O = 8	O = 8		O = 4	O = 4
Si	2.382	2.408	3.012		0.981	1.014
Ti	0.005	0.005	0.000		0.000	0.001
Al	1.574	1.556	0.960		0.000	0.000
Fe	0.023	0.020	0.030		0.182	1.866
Mn	0.000	0.000	0.001		0.010	0.084
Mg	0.011	0.009	0.000		1.837	0.005
Ca	0.644	0.609	0.000		0.004	0.014
Na	0.356	0.385	0.655		0.000	0.000
K	0.014	0.015	0.354		0.000	0.000
Ni	0.000	0.000	0.000		0.004	0.000
Cr	0.000	0.000	0.001		0.001	0.000
V	0.000	0.000	0.000		0.000	0.000
total	5.011	5.009	5.012		3.019	2.985
An	63.50	60.32	0.03	Fo	90.98	0.25
Ab	35.14	38.18	64.90			
Or	1.36	1.50	35.07			

1: core of plagioclase microphenocryst in 82083101 (olivine basalt)
2: rim of "1"
3: core of sanidine phenocryst in 82100404 (alkali rhyolite)
4: core of olivine phenocryst in N-32 (olivine basalt)
5: core of olivine phenocryst in 82100404 (alkali rhyolite)

Table 2 (continue)

	CLINOPYROXENE						
	6	7	8	9	10	11	12
SiO_2	50.52	50.37	48.72	45.31	44.11	51.68	44.77
TiO_2	0.69	1.17	2.04	4.22	5.85	0.51	2.84
Al_2O_3	0.63	3.87	4.71	6.43	5.77	3.93	9.42
FeO	20.70	4.77	6.64	10.14	12.96	3.63	7.05
MnO	1.03	0.12	0.20	0.21	0.25	0.11	0.11
MgO	5.18	15.27	14.46	11.38	8.94	16.16	11.99
CaO	18.07	22.33	21.77	20.68	19.59	22.10	22.73
Na_2O	2.36	0.32	0.65	0.51	0.78	0.42	0.43
K_2O	0.03	0.00	0.00	0.01	0.00	0.01	0.01
NiO	0.04	0.05	0.06	0.00	0.00	0.00	0.00
Cr_2O_3	0.00	0.80	0.08	0.11	0.00	1.35	0.31
V_2O_3	0.00	0.03	0.01	0.13	0.04	0.00	0.00
total	99.25	99.10	99.33	99.15	98.29	99.91	99.67
	O = 6	O = 6	O = 6	O = 6	O = 6	O = 6	O = 6
Si	2.010	1.872	1.825	1.733	1.725	1.891	1.685
Ti	0.021	0.033	0.057	0.121	0.172	0.014	0.080
Al	0.030	0.170	0.208	0.290	0.266	0.170	0.418
Fe	0.689	0.148	0.208	0.324	0.424	0.111	0.222
Mn	0.035	0.004	0.006	0.007	0.008	0.003	0.004
Mg	0.308	0.846	0.807	0.649	0.521	0.881	0.672
Ca	0.770	0.889	0.874	0.847	0.821	0.866	0.916
Na	0.182	0.023	0.047	0.038	0.060	0.030	0.032
K	0.001	0.000	0.000	0.001	0.000	0.000	0.001
Ni	0.001	0.002	0.002	0.000	0.000	0.000	0.000
Cr	0.000	0.023	0.002	0.004	0.000	0.039	0.009
V	0.000	0.001	0.000	0.004	0.001	0.000	0.000
total	4.084	4.010	4.037	4.018	3.998	4.006	4.038
Wo	43.60	47.20	46.25	46.55	46.48	46.61	50.61
En	17.41	44.92	42.74	35.64	29.50	47.41	37.14
Fs	38.99	7.88	11.01	17.82	24.01	5.98	12.25
Mg/Mg+Fe	0.309	0.851	0.795	0.667	0.551	0.888	0.752

6: core of aegirine augite microphenocryst in 82100901 (sodalite trachyte)
7: core of clinopyroxene phenocryst in N-32 (olivine basalt)
8: rim of "7"
9: core of clinopyroxene microphenocryst in 82083101 (olivine basalt)
10: rim of "9"
11: core of clinopyroxene phenocryst in 82093001 (ankaramite)
12: rim of "11"

82092817 (Aka Aiteputh Formation): This rock is characterized by very abundant olivine and augite phenocrysts (about 40 vol.%) and by magnesian character of its bulk chemistry (16% MgO, FeO*/MgO less than 0.6). Olivine is partly replaced by serpentine. Groundmass shows intersertal texture. It is composed of euhedral to subhedral plagioclase, titanaugite, olivine and an opaque mineral with interstitial zeolite, alkali feldspar and a green clay mineral. A small amount of secondary carbonate mineral occurs in the groundmass.

Table 3

Representative bulk chemical data determined by XRF

Sample No.	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
82083101	47.64	3.05	15.47	12.11	0.19	6.26	11.19	2.57	0.97	0.55
82100407	49.55	3.19	13.68	14.23	0.21	4.79	10.10	2.92	1.04	0.28
82100406	50.54	2.29	17.13	11.01	0.20	3.84	10.00	3.35	1.29	0.36
82100404	70.19	0.58	11.91	8.28	0.28	0.02	0.67	3.79	4.30	0.00
82100403	48.51	3.06	14.90	13.84	0.20	5.60	9.60	2.96	1.05	0.27
N-32	47.77	2.13	13.37	9.92	0.15	12.25	10.67	1.86	1.50	0.38
82082501	48.46	2.39	17.44	10.67	0.17	5.86	9.69	3.25	1.66	0.41
82083104	47.51	1.55	10.02	11.60	0.17	16.14	10.88	1.54	0.42	0.15
82083106	47.66	1.43	9.13	11.47	0.17	16.83	11.52	1.34	0.35	0.10
82083107	48.52	2.71	18.32	11.15	0.17	4.78	9.14	2.88	1.85	0.49
82083108	49.00	2.73	17.61	11.09	0.17	4.93	9.07	3.07	1.82	0.52
82083109	48.56	2.41	17.62	10.68	0.17	6.01	9.40	3.20	1.55	0.41
82083110	47.85	2.56	16.07	11.91	0.17	6.70	10.56	2.80	1.13	0.26
82083111**	56.28	1.59	16.97	9.28	0.22	1.86	5.20	4.85	3.31	0.42
82100103	47.83	2.33	17.40	11.13	0.17	5.70	10.79	3.39	1.04	0.22
82100104	48.97	2.72	17.65	11.04	0.18	5.15	8.49	3.54	1.80	0.48
82100105	48.10	2.37	17.23	10.58	0.17	5.79	9.39	4.34	1.66	0.39
82100110	44.79	2.61	14.47	13.34	0.24	6.99	13.07	3.26	1.03	0.22
82092801	47.83	2.27	17.28	11.27	0.18	6.26	10.15	3.10	1.35	0.31
82092803	48.13	2.29	18.00	11.02	0.17	5.10	10.35	3.13	1.47	0.34
82092804	46.11	2.03	13.46	10.86	0.18	11.94	11.85	2.81	0.49	0.27
82092806	47.93	2.32	18.30	10.32	0.19	5.85	10.70	2.69	1.37	0.34
82092812	46.59	2.05	15.45	11.32	0.18	7.12	12.92	2.93	1.14	0.29
82092814	46.57	2.25	15.58	11.03	0.19	8.42	11.49	3.26	0.84	0.37
82092817	46.04	1.46	10.00	9.38	0.15	16.03	14.15	2.20	0.51	0.09
82092818	46.36	2.46	16.70	11.82	0.20	6.10	11.52	3.15	1.06	0.61
82093001	46.05	1.70	12.22	10.14	0.18	13.26	11.47	3.65	1.17	0.17
82100901	62.51	0.68	14.80	9.14	0.36	0.57	1.68	5.18	4.92	0.17
82100903	46.96	2.03	15.28	10.10	0.19	8.43	11.44	3.73	1.55	0.28
82101501	46.49	2.57	15.88	12.68	0.19	6.90	12.21	1.91	0.88	0.29
82101504	46.13	3.25	15.29	13.74	0.21	6.15	10.99	2.46	1.17	0.61
82101202***	47.22	1.65	16.73	10.33	0.16	7.18	13.57	2.46	0.59	0.12

* total Fe as FeO

** aphyric trachytic hawaiite

*** younger olivine-augite alkali basalt in the Baragoi Area

See text for petrography of other rocks

82083106 (Kongia Formation): This rock has normative hypersthene and deviates from a typical ankaramite in its chemistry (Table 3), but in this paper it is called ankaramite for convenience. It possesses ophytic texture with augite, olivine, plagioclase and subordinate opaque minerals and glass. The plagioclase is usually lath-shaped. The olivine and augite are usually anhedral, rarely euhedral. Augite often encloses plagioclase laths poikilitically. Large olivine and augite crystals are tentatively interpreted as phenocrysts. The total amount of phenocrysts is about 40%. Olivine is usually altered to serpentine or iddingsite. Glass is usually altered to a green clay mineral.

(ii) Olivine basalt

Most of the olivine basalts in the Samburu District have normative nepheline and a few have normative hypersthene. The hypersthene normative basalts commonly contain titanaugite and have characteristics transitional between alkali and tholeiitic basalts. Olivine basalts usually carry olivine and augite phenocrysts (0 to 20 vol.%), but rarely also have significant amounts of plagioclase phenocrysts. Some lava flows of this rock type contain ultrabasic nodules.

82101504* (Nachola Formation): This rock carries no phenocrysts other than small amounts of plagioclase microphenocrysts. Its groundmass shows an intergranular texture. It is composed of lath-shaped plagioclase, euhedral to subhedral olivine, titanaugite and an opaque mineral and a subordinate amount of apatite and interstitial alkali feldspar. A small amount of clay minerals, which may be altered glass, occurs in the interstices. Olivine is partly replaced by iddingsite.

82101501* (Nachola Formation): This rock carries small amounts of olivine, plagioclase and augite microphenocrysts, which often possess glomeroporphyritic texture. In such cases olivine and augite are usually anhedral. Olivine is partly altered to iddingsite, while other minerals are quite fresh. Groundmass shows an intergranular texture. It is composed of lath-shaped plagioclase, euhedral olivine, titanaugite and a subhedral opaque mineral and interstitial alkali feldspar and zeolite. Glass is rarely observed in the interstices. Zeolite in a druse also occurs in this sample.

82100114* (Aka Aiteputh Formation): This lava is characterized by abundant euhedral plagioclase phenocrysts. It also carries subhedral augite, magnetite and olivine phenocrysts. The augite shows conspicuous pleochroism from pinkish brown to pale green. Augite and plagioclase are sometimes deeply embayed. Olivine is usually replaced by iddingsite. Groundmass shows intersertal to intergranular texture. It is composed of lath-shaped plagioclase, euhedral olivine, titanaugite, an opaque mineral and subordinate amounts of apatite, and interstitial alkali feldspar, zeolite and glass. The glass is usually altered to a green clay mineral. Apatite also occurs as inclusions in plagioclase, augite or olivine phenocrysts.

82100113* (Aka Aiteputh Formation): This rock contains euhedral to subhedral augite, olivine and small amounts of plagioclase phenocrysts. The olivine is partly altered to iddingsite. The augite shows pleochroism from pinkish brown to pale green and is sometimes rounded. Magnetite inclusions are sometimes found in olivine and augite phenocrysts. Groundmass possesses an intergranular texture. It is composed of lath-shaped plagioclase and euhedral titanaugite, olivine and an opaque mineral, and interstitial alkali feldspar. Brown glass is rarely observed in the interstices.

N-32 (Nagubarat Formation): This rock is the most magnesian rock in the district with the exception of ankaramites. Phenocrysts are composed of euhedral to subhedral olivine and augite. Euhedral chromian spinel and magnetite occur enclosed by olivine and/or augite phenocrysts. Olivine sometimes encloses dendritic magnetite. Groundmass, which shows intersertal texture, is composed of lath-shaped plagioclase and anorthoclase, euhedral olivine, titanaugite, an opaque mineral and subordinate apatite, and interstitial alkali feldspar, analcite, glass and cossyrite. Two types of glass (brown and colorless) are observed. Small spheres of brown glass (about 1 μm in diameter) occur enclosed in colorless glass, indicating liquid immiscibility at the later stage of solidification of a magma (Philpotts, 1979; Fujii *et al.*, 1980). Analcite syenite occeli (Philpotts,

*Samples used for K-Ar age determinations.

1978), up to several mm in diameter are observed in some slices of this rock.

This rock sometimes carries fragments of ultrabasic rock (mainly dunite and wehrlite) and felsic plutonic rock made of mainly quartz and sodic plagioclase. The felsic fragments are presumed to have originated from the Pre-Cambrian Basement. The quartz and sodic plagioclase crystals are corroded and enclosed by fine-grained clinopyroxene jackets.

82083101 (A scoria cone in the Suguta Valley): This rock contains small amounts of olivine, titanaugite and plagioclase microphenocrysts (2 vol.% as a whole). These minerals sometimes show glomeroporphyritic textures. Plagioclase microphenocrysts contain inclusions of euhedral olivine, titanaugite or an opaque mineral. Porous groundmass shows intersertal to intergranular texture. It is composed of lath-shaped or acicular plagioclase, acicular titanaugite, euhedral olivine, an opaque mineral and subordinate apatite and interstitial alkali feldspar and brown glass.

(iii) Hawaiite

Basaltic rocks with relatively leucocratic groundmass are here named hawaiite. Plagioclase is often a dominant phase of phenocryst in this type of rock.

82100106* (Kongia Formation): This rock is aphyric, carrying small amounts of plagioclase and olivine microphenocrysts (less than 1 vol.%). Some plagioclase microphenocrysts contain abundant glass inclusions. Groundmass possesses an intergranular texture. It is composed of lath-shaped plagioclase and euhedral olivine, titanaugite, an opaque mineral and subordinate apatite, and interstitial glass and alkali feldspar. Olivine is sometimes replaced by iddingsite or a clay mineral. Secondary chalcedony often fills druses or replaces the interstitial glass.

82082401* (Kongia Formation): This rock is nearly aphyric. There are aggregates of a fine opaque mineral, clinopyroxene and feldspar up to 0.1 mm in diameter, which may be break-down products of hornblende. Groundmass shows an intergranular to intersertal texture. It is composed of lath-shaped plagioclase, and euhedral titanaugite, olivine, an opaque mineral and apatite, euhedral to subhedral cossyrite and hornblende, and interstitial alkali feldspar and analcite. Olivine is usually altered to iddingsite. Small amounts of a green clay mineral, which is presumed to be altered glass, occur in the interstices. Small amounts of secondary carbonate mineral occur in the groundmass.

82083113 (Kongia Formation): This rock contains abundant plagioclase (about 30 vol.%) and small amounts of olivine and titanaugite phenocrysts. The olivine is usually replaced by a carbonate mineral. Plagioclase crystals are up to 1 cm in length and contain the inclusions of glass, titanaugite, olivine or opaque minerals. Groundmass shows a subophytic texture. It is composed of lath-shaped plagioclase and anorthoclase, and euhedral or anhedral titanaugite, olivine, opaque minerals and apatite, and anhedral alkali feldspar, analcite and a secondary green clay mineral. Alkali feldspar sometimes occurs fringing plagioclase.

Phenocryst assemblages and modal abundances

Basaltic rocks including ankaramite and hawaiite contain 0% to 40% phenocrysts of olivine, clinopyroxene and plagioclase. Magnetite microphenocrysts occur sparcely in some samples. In magnesian basaltic rocks of the Suguta Area (here defined by FeO*/MgO less than 3.0 in bulk composition), the total volume percent of phenocrysts, modal ratio among olivine, clinopyroxene and plagioclase phenocrysts and FeO*/MgO ratio of the groundmass are illustrated in Fig. 2. The chemical composition of the groundmass is estimated by subtracting chemical compositions of phenocrysts from a bulk chemical composition.

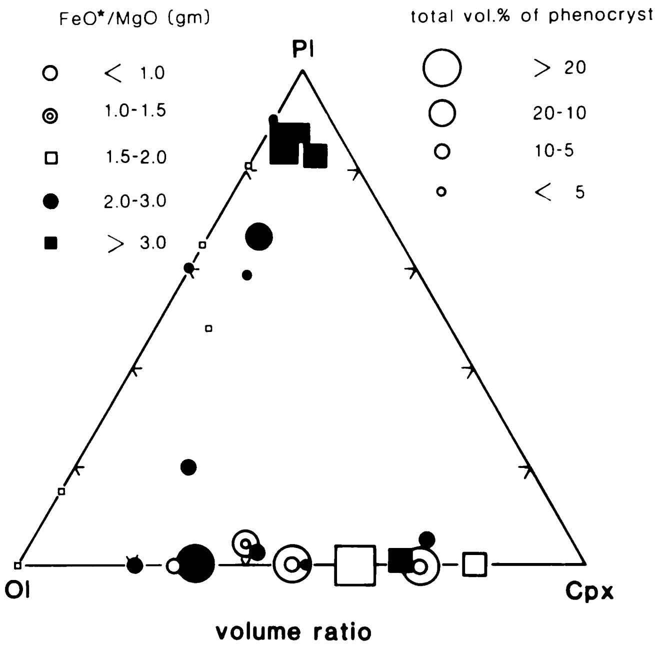

Fig. 2: Modal ratio among olivine (ol), clinopyroxene (cpx) and plagioclase (pl) phenocrysts of magnesian basaltic rocks. Total volume percent of phenocrysts is expressed by the size of symbols.

Phenocrysts in rocks which contain less than 5 vol.% of phenocrysts are generally small and there is size continuity between the phenocrysts and the groundmass crystals. For such samples crystals more than 0.2 mm in length are tentatively called phenocrysts. In contrast there is no size continuity between the phenocrysts and the groundmass crystals in rocks with more than 5 vol.% of phenocrysts. Phenocrysts in rocks with less than 5 vol.% of phenocrysts may have crystallized at the same time as the groundmass, while those in rocks with more than 5 vol.% of phenocrysts, on the other hand, would represent phases which crystallized in a magma chamber. Among rocks with more than 5 vol.% of phenocrysts, plagioclase is abundant only in rocks with a relatively iron rich groundmass (FeO*/MgO ratio is more than 2.0) (Fig. 2). Rocks with a relatively magnesian groundmass (FeO*/MgO less than 2.0) have a phenocryst assemblage consisting of olivine + clinopyroxene (Fig. 2). The FeO*/MgO ratio represents the degree of fractional crystallization, because fractionation of ferro-magnesian minerals results in substantial increase of FeO*/MgO in the residual liquid. Consequently it is inferred that the phenocryst assemblage changed from olivine + clinopyroxene to olivine + clinopyroxene + plagioclase during crystallization of the magma. Olivine may precipitate first in a primary magma after the segregation from mantle peridotite, because primary magmas should be saturated with olivine during partial melting, and because the olivine primary field expands as pressure decreases. Thus it is concluded that the crystallization sequence of the basaltic magma of the Samburu District was olivine to clinopyroxene to plagioclase.

Grain size distribution of phenocrysts

The grain size distribution of phenocrysts is here determined for those samples with more than

5 vol.% of phenocrysts. The length of each phenocryst was measured in thin sections. In general, because a thin section does not cut through the central part of the phenocryst, lengths of crystals are underestimated. We can, therefore, detect only relative differences between samples. Olivine, clinopyroxene and plagioclase phenocrysts have a similar aspect ratio (1 to 3), but most magnetite microphenocrysts have an aspect ratio of nearly 1. Phenocryst distribution within a sample is megascopically isotropic so that the modal analyses and the obtained grain size distribution are considered to be independent of the orientation of the section.

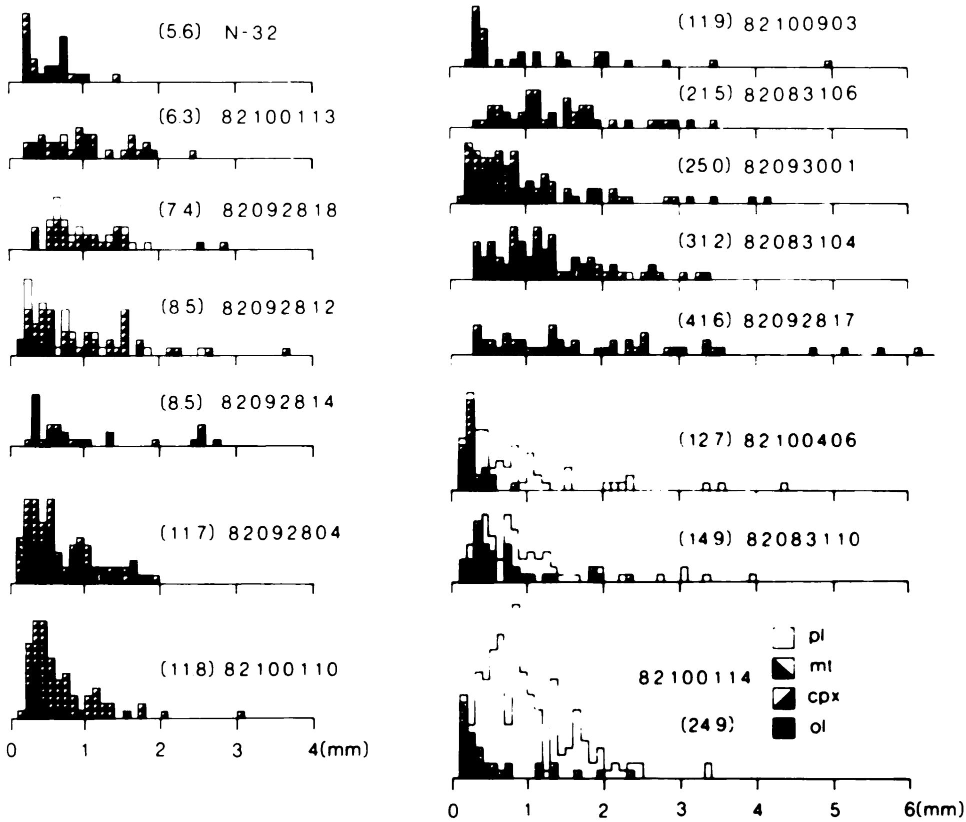

Fig. 3: Size distribution of phenocrysts of magnesian basaltic rocks. Numbers in parentheses indicate total volume percent of phenocrysts in each sample. pl: plagioclase. mt: magnetite. cpx: clinopyroxene. ol: olivine.

Two features can be recognized in Fig. 3. (1) Plagioclase is larger than olivine or clinopyroxene within a given sample (e.g. 82100114). (2) The samples with smaller amounts of phenocrysts are depleted in large phenocrysts in comparison with phenocryst-rich samples. Assuming that the original magma has the same initial size distribution of phenocrysts, subsequent magmas with smaller amounts of phenocrysts would be selectively depleted in large or dense phenocrysts. This is considered to result from the fact that larger or denser phenocrysts have a greater terminal velocity, and would be selectively fractionated from the magma.

Mineralogy

Representative analyses of phenocrystic minerals in basaltic rocks are listed in Table 2.

Olivine: Olivine is common especially in magnesian basalts and ankaramites. In most samples it is less than 2 mm in diameter, but in a few ankaramites it attains a size of 5 mm. Picotite inclusions are commonly found. Two kinds of zoning are recognized. Olivine in basaltic rocks is usually characterized by gentle normal zoning at the core which is surrounded by a narrow rim which is strongly zoned (Fig. 4 type-B). In ankaramites, on the other hand, olivine phenocrysts generally have a large flat core (up to 5 mm in diameter) with a normally zoned rim (Fig. 4 type-A).

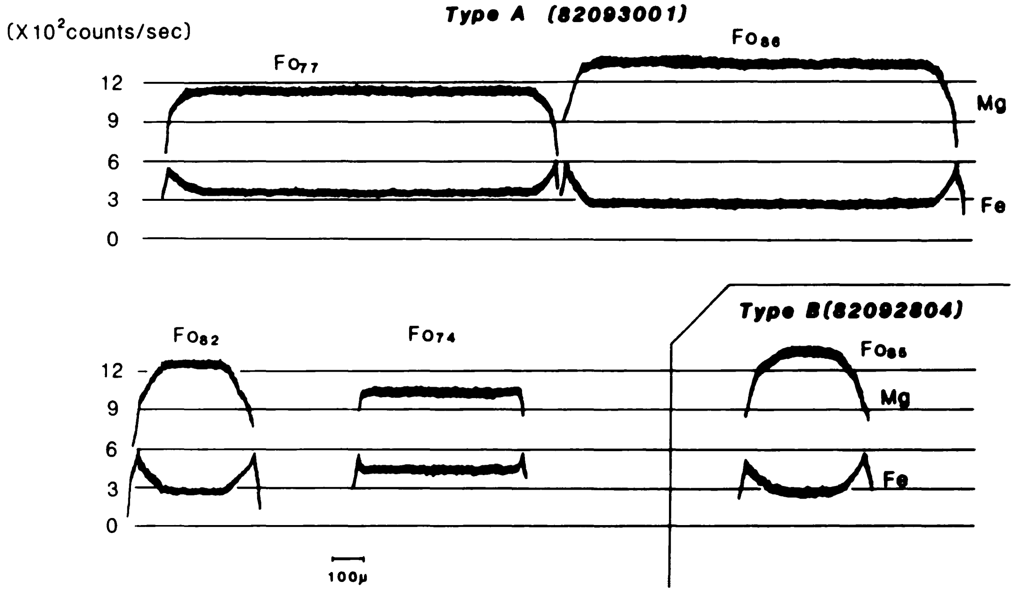

Fig. 4: Zoning profiles of olivine phenocrysts. For definitions of "type-A" and "type-B" see text.

The zoning profile of type-B olivine crystals is similar to the pattern of growth zoning which is obtained numerically (Maaløe and Hansen, 1982; Sato and Banno, 1983). That of type-A crystals, however, seems not to be explained by the growth zoning. Diffusion homogenization would have affected the profile (Koyaguchi in prep.). The forsterite content of each flat core of type-A crystals varies from crystal to crystal within a single sample.

The forsterite content of the core is roughly correlated to the bulk chemical composition, that is, the more magnesium rocks carry the more magnesian olivine phenocrysts. The ratio of FeO/MgO in olivine and FeO/MgO in bulk chemical composition (K-value) is around 0.3 in sample N-32 (Fig. 5). Roeder and Emslie (1970) proposed that Mg-Fe exchange coefficient between basaltic liquid and the coexisting olivine is about 0.3 for a wide range of temperatures and chemical compositions. The bulk chemical composition of N-32, therefore, probably represents the chemical composition of the liquid in which the core of the olivine phenocrysts was crystallized.

Clinopyroxene (augite): Clinopyroxene is similar or larger in size than olivine phenocrysts and is sometimes up to 2 cm long in ankaramites. Clinopyroxene has a generally flat or mildly normally zoned core with the rim showing conspicuous normal zoning. The Mg/Mg+Fe ratio of the core is generally similar to that of coexisting olivine phenocrysts. Hourglass structure is common especially in microphenocrystic clinopyroxene.

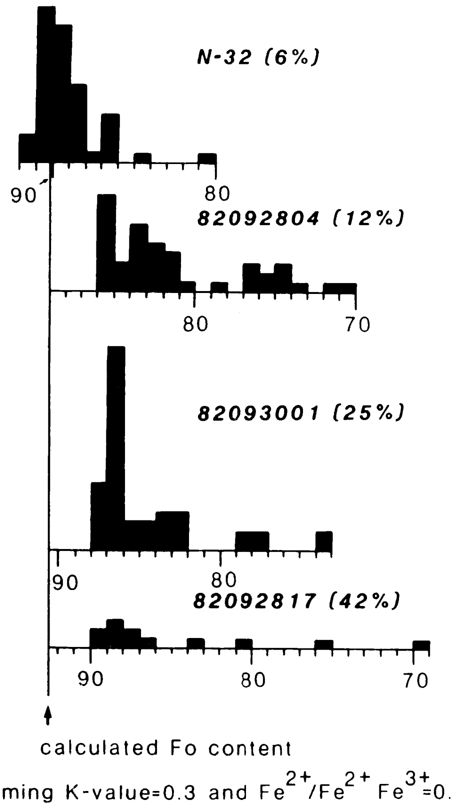

Fig. 5: Frequency diagram of forsterite content of core of olivine phenocrysts. Total volume percent of each sample is also shown.

The Al_2O_3 and TiO_2 content increases with decrease of the Mg/Mg+Fe ratio, namely from core to rim except in sample 82083101 where the Al_2O_3 content decreases from core to rim (Fig. 6). The rate of enrichment of either the Al_2O_3 or the TiO_2 content against decreasing Mg/Mg+Fe is not variable among the analyzed samples and is independent of the degree of silica-undersaturation of the host rocks, i.e. normative nepheline content (Fig. 6).

Plagioclase: Plagioclase phenocrysts are common especially in hawaiite. Plagioclase possesses flat or mildly normal zoning. The anorthite content of the core varies from sample to sample from An_{70} to An_{50}.

(2) Differentiated Rocks

Differentiated rocks from the Samburu District are divided into four types based on their petrographic features and mode of emplacement.

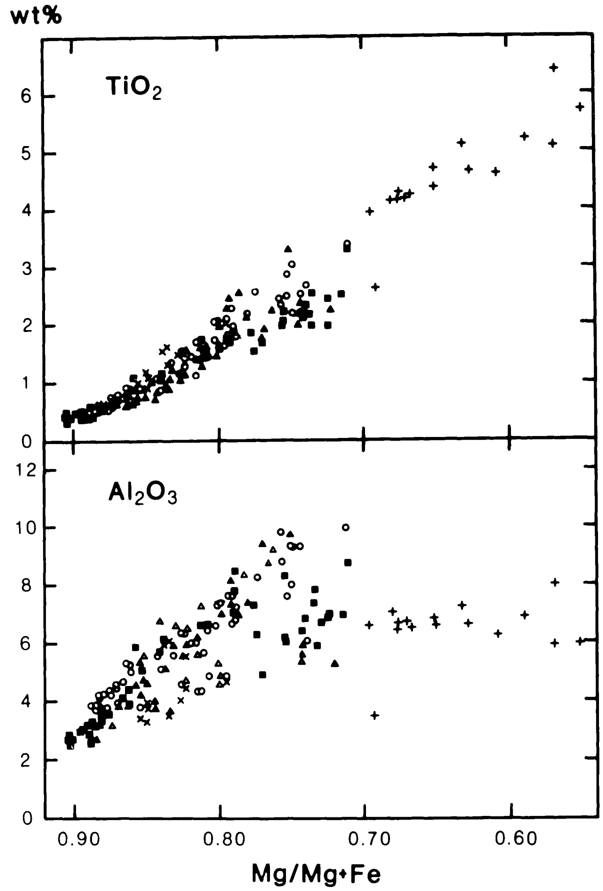

Fig. 6: Al_2O_3 and TiO_2 content against Mg/Mg+Fe mole ratio of clinopyroxene phenocrysts of basaltic rocks with variable normative nepheline contents (wt% ne.) Symbol +; 82083101 (0 wt% ne). Symbol x; N-32 (0.23 wt% ne). Open circle; 82092804 (6.78 wt% ne). Solid square; 82092817 (9.90 wt% ne). Open triangle; 82093001 (15.6 wt% ne).

(i) Phonolitic trachyte lava flow (Nachola Formation)
(ii) Sodalite trachyte lava flow (Aka Aiteputh Formation)
(iii) Trachyte welded tuff (Nachola and Aka Aiteputh Formations)
(iv) Alkali rhyolite lava flow (Tirr Tirr Formation)

(i) Phonolitic trachyte lava flow

Phonolitic trachyte lava flows occur about 1 km west of Nachola Village and form flat topographic features. They contain anorthoclase, ferroaugite, olivine, magnetite and apatite phenocrysts. Anorthoclase occurs as long prismatic crystals, up to 1 cm in length. It is characterized by conspicuous twinning. Ferroaugite and olivine are euhedral and up to 0.2 mm in length. Olivine is commonly replaced by a carbonate mineral. Magnetite and apatite are euhedral and up to 0.1 mm in size. Ferroaugite, magnetite and apatite are often enclosed by a large anorthoclase phenocryst.

Groundmass usually possesses intersertal texture and is composed of lath-shaped or acicular anorthoclase and euhedral clinopyroxene, magnetite and apatite and interstitial brown and colorless glass, cossyrite, and zeolite. Acicular anorthoclase enclosing fine-grained opaque minerals and glass often forms spherulites up to several mm in diameter. This rock corresponds to the phonolite lava flow depicted in Baker's geological map (1963). It is here considered to be a variety of trachyte, because of the scarcity of modal nepheline and its relatively low alkalinity.

(ii) Sodalite trachyte lava flow

Several lava flows of sodalite trachyte occur in the eastern part of the Suguta Area. They contain no phenocrysts but small amounts of microphenocrystic sodalite and anorthoclase are present. Some sodalite microphenocrysts have decomposed to form aggregates of fine-grained nepheline. Groundmass shows trachytic texture and is composed of lath-shaped anorthoclase, anhedral aegirine augite and small amounts of glass, opaque minerals, sodalite and zeolite.

(iii) Trachyte welded tuff

A red trachyte welded tuff about 20 m thick occurs in the eastern part of the Suguta Area. It contains sanidine phenocrysts and essential fragments. The essential fragments, which are up to several tens of cm in size, contain prismatic sanidine phenocrysts several mm in length. Most of the fragments are glassy, but some are crystalline and possess a trachytic texture. The groundmass of the fragments is composed of lath-shaped alkali feldspar, euhedral to anhedral aegirine augite, cossyrite and apatite. Matrix is composed of glass and sanidine fragments. Eutaxitic texture is common, especially in densely welded parts. Thin gray layers of trachyte welded tuff often occur in the Nachola Formation and in the upper part of the Aka Aiteputh Formation.

Table 4
Wet chemical analyses for selective samples

	82092502	82100114	82100113	82100106	82100101	82082401
SiO_2	55.47	49.03	43.95	46.76	49.70	49.23
TiO_2	1.37	2.37	2.42	2.43	2.63	3.07
Al_2O_3	15.36	18.38	15.63	17.16	15.83	15.60
Fe_2O_3	2.92	3.26	4.28	3.72	5.17	3.83
FeO	4.70	5.84	8.23	7.09	5.63	7.74
MnO	0.25	0.17	0.20	0.18	0.18	0.21
MgO	1.10	3.21	7.23	5.27	3.02	3.61
CaO	3.06	9.14	12.23	8.74	6.67	6.95
Na_2O	4.93	4.31	2.71	4.18	4.83	5.13
K_2O	4.98	1.25	0.78	1.35	2.45	1.85
P_2O_5	0.33	0.87	0.49	0.54	1.02	0.55
H_2O (−)	1.30	0.18	0.10	0.10	0.18	0.15
H_2O (+)	4.11	2.02	2.40	2.83	3.32	2.57
total	99.88	100.03	100.65	100.35	100.63	100.49

82092502; phonolitic trachyte (Nachola Foramtion) analyzed by H. Haramura
82100114; alkali basalt (Aka Aiteputh Formation)
82100113; alkali basalt (Aka Aiteputh Formation)
82100106; hawaiite (Kongia Formation)
82100101; hawaiite (Kongia Formation)
82082401; hawaiite (Kongia Formation)

(iv) Alkali rhyolite lava flow

An alkali rhyolite lava flow up to 20-30 m in thickness occurs in the Tirr Tirr Plateau north of the Samburu Hills. It possesses a porphyritic texture with prismatic sanidine and small amounts of euhedral fayalite and aegirine augite phenocrysts. These phenocrysts are up to 5 mm long. Groundmass is usually glassy and rarely crystalline with a trachytic texture. It contains sanidine, opaque minerals, clinopyroxene and an unidentified fine-grained mineral which is thought to be devitrified glass. This rock was called trachyte by Baker (1963), but is here considered to be an alkali rhyolite because of its high silica content (about 70%).

Selective chemical compositions of these differentiated rocks are listed in Tables 3 and 4. Some chemical compositions of the constituent minerals are listed in Table 2.

BULK CHEMISTRY

Representative major element data listed in Table 3 were analyzed by XRF and were recalculated to give a total of 100%. Wet chemical analyses of selective samples are listed in Table 4. Most of the data points fall into the region of the alkaline rock suite as defined by Macdonald and Katsura (1964) (Fig. 7).

Most of the basalts have normative nepheline assuming that $Fe^{2+}/Fe^{2+} + Fe^{3+} = 1.0$. Basalts

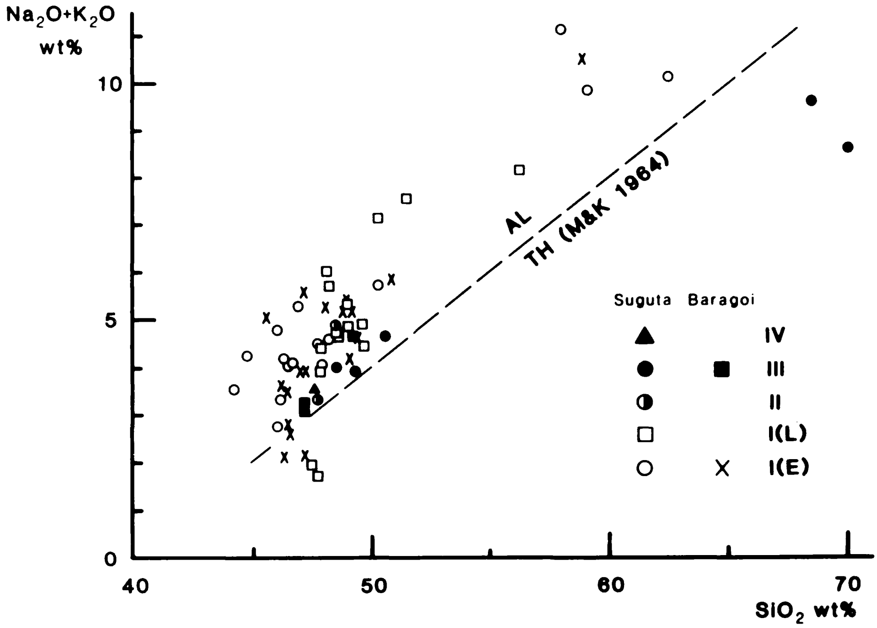

Fig. 7: SiO_2 vs Alkali diagram showing relative distributution of volcanic rocks belonging to each stage in the Suguta Area. I(E); The earlier substage of Stage I. I(L); The later substage of Stage I. II; Stage II. III; Stage III. IV; Stage IV. Volcanic rocks of the Nachola Formation (X) and the younger basaltic lava flows (solid square) in the Baragoi Area are also plotted. Dashed line is the boundary between alkalic and tholeiitic rock suites as defined by Macdonald and Katsura (1964).

of the Kongia and the Tirr Tirr Formations and those in the Suguta Valley have normative hypersthene. The trachytes usually have normative hypersthene. The alkali rhyolite has normative quartz.

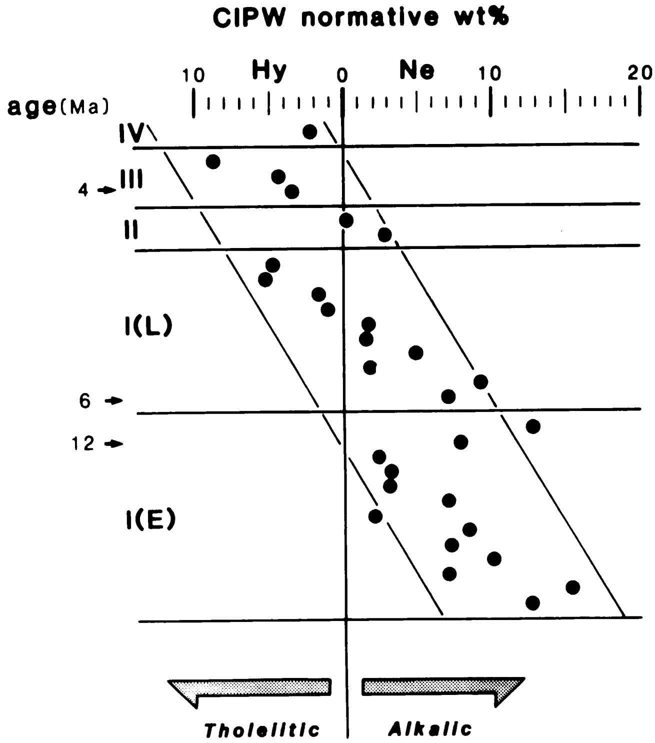

Fig. 8: Normative nepheline/hypersthene content of magnesian basaltic rocks plotted against stratigraphic sequence in the Suguta Area.

Fig. 8 shows the variation in degree of silica-undersaturation for basaltic rocks with less than 3.0 of FeO*/MgO ratio plotted against stratigraphic sequence in the Suguta Area. The pattern which results indicates a strictly temporal variation, because the samples were obtained from a small area of 10 x 10 km^2 for which the effect of spatial variation can be considered to be negligible. A decrease in degree of silica-undersaturation with time is observed. Similar patterns have been recognized in the north Kenya and other rift systems by Lippard and Truckle (1978), Baker *et al.* (1978), and Mohr (1970).

A decrease in alkalinity in differentiated rocks ranging from trachytes (Stage I) to alkali rhyolite (Stage III) can be recognized (Fig. 7). Phonolitic trachyte and sodalite trachyte are closely associated with highly undersaturated ankaramites or basanitoids, while alkali rhyolite occurs in close association with hypersthene normative basalts. This close relation between the chemical natures of the basaltic and the differentiated rocks which erupted within a short period from a rift sector is reported from many places in the East African Rift (e.g. Barberi *et al.* 1982).

In the AFM diagram (Fig. 9) Stage III basalts show more conspicuous enrichment in FeO* than those of Stage I, reflecting their lower alkalinity.

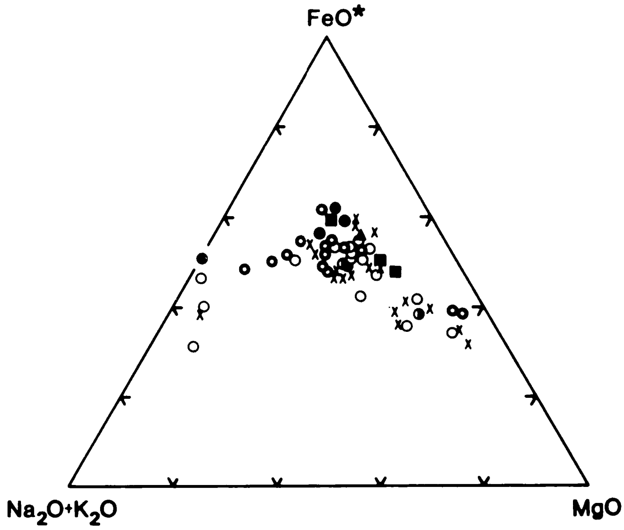

Fig. 9: Alkali-FeO*-MgO diagram showing relative distribution of volcanic rocks of each stage. Symbols are the same as those in Fig. 7.

In Fig. 8 the vertical axis shows relative stratigraphic positions, but the spacing does not indicate any real time duration. There is a large hiatus of 6 million years between the two substages of Stage I. This hiatus in volcanism appears to be common in the northern part of the Kenya Rift judging from the data compiled by Baker *et al.* (1971). Lavas which erupted just after and just before the hiatus have a similar normative nepheline content (Fig. 8).

IMPLICATION OF THE TEMPORAL VARIATION IN THE CHEMISTRY OF THE BASALTIC ROCKS

The temporal variation in the chemical composition of lavas shown in Fig. 8 is considered to reflect that of primary magmas which were segregated from mantle peridotite, because the effect of fractional crystallization on the degree of silica-undersaturation of the bulk chemistry is insignificant for basaltic rocks with FeO*/MgO less than 3.0. The effects of fractional crystallization and phenocrystic accumulation on the bulk chemistry will be discussed in detail by Koyaguchi (in prep.).

Takahashi and Kushiro (1983) proposed a normative diagram which shows the relationship between the pressure where primary magmas segregated from the upper mantle and their chemical compositions which are normatively plotted (Fig. 10). The normative nepheline content of a primary magma increases with an increase in pressure. It also increases with a decrease of the degree of partial melting.

Basaltic rocks with FeO*/MgO less than 3.0 are plotted in Fig. 10. They are distributed across the isobaric liquid lines indicating successive decrease in depth of segregation of primary magmas from the mantle peridotite.

The depth of the segregation would depend mainly on the depth where diapiric uprise of

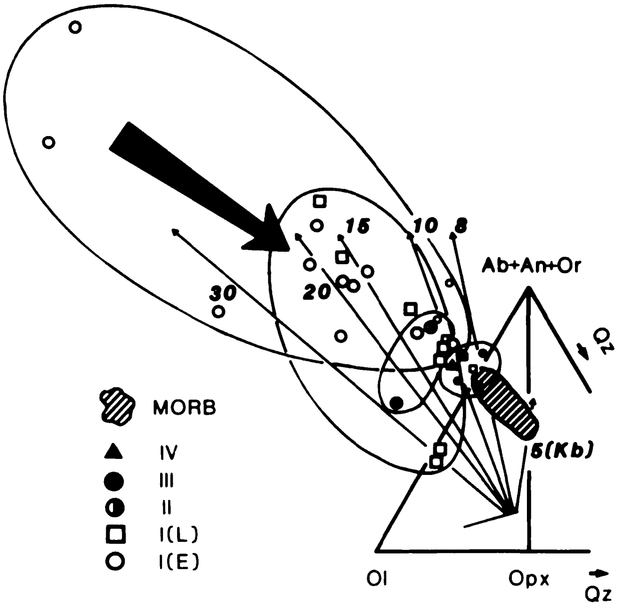

Fig. 10: Normative compositions of magnesian basaltic rocks in the Suguta Area (symbols are the same as those in Fig. 7). The isobaric compositional trend of primary magma (solid line) is from Takahashi *et al.* (1981) in ternary projection by Walker *et al.* (1979). Projected from diopside onto olivine-plagioclase-quartz plane. Large symbols; rocks with FeO*/MgO less than 2.0. Small symbols; rocks with FeO*/MgO between 2.0 and 3.0. Ab: albite, An: anorthite, Or: orthoclase, Oz: quartz, Ol: olivine, Opx: orthopyroxene.

mantle comes to a stop. There are at least two possible boundaries where the diapiric uprise may stop. The crust-mantle boundary is the most important boundary through which a mantle diapir is unable to move upward by buoyant force alone. The asthenosphere-lithosphere boundary would be the other important boundary where the viscosity of the mantle abruptly changes. Numerous studies on gravity and seismicity indicate that a zone of low velocity material reaches just below the crust (about 30 km in depth) beneath the East Africa Rift (Searle, 1970; Baker and Wohlenberg, 1971; Fairhead and Girdler, 1972; Fairhead, 1976; Long *et al.*, 1972; Long and Backhouse, 1976). Both boundaries, therefore, are consistent with the depth of segregation of the primary magmas of the recent basalts in the Samburu District. Maguire and Long (1976) estimated the crustal thickness away from the rift to be 46 km at most. On the other hand thickness of lithosphere away from the rift can be assumed to be around 100 km (Press, 1979; Fairhead, 1976; Knopoff and Schule, 1972). At the onset of volcanism in the rift, the boundary between the lithosphere and the asthenosphere seems to have played a role in stopping diapiric uprise, judging from the depth of segregation of magmas (about 100 km in depth). The temporal variation in the basalt chemistry can, therefore, be inferred to be related to the thinning of lithosphere (crust + lithospheric mantle).

Variation in the degree of partial melting cannot be estimated at present. Assuming the adiabatic uprise of the mantle diapir, as the diapir rises, the pressure decreases and the degree of partial melting increases. Both factors, (1) the successive decrease of pressure and (2) the successive increase of degree of partial melting, may operate at the same time and would result in the successive decrease in degree of silica-undersaturation of the basaltic rocks of this district.

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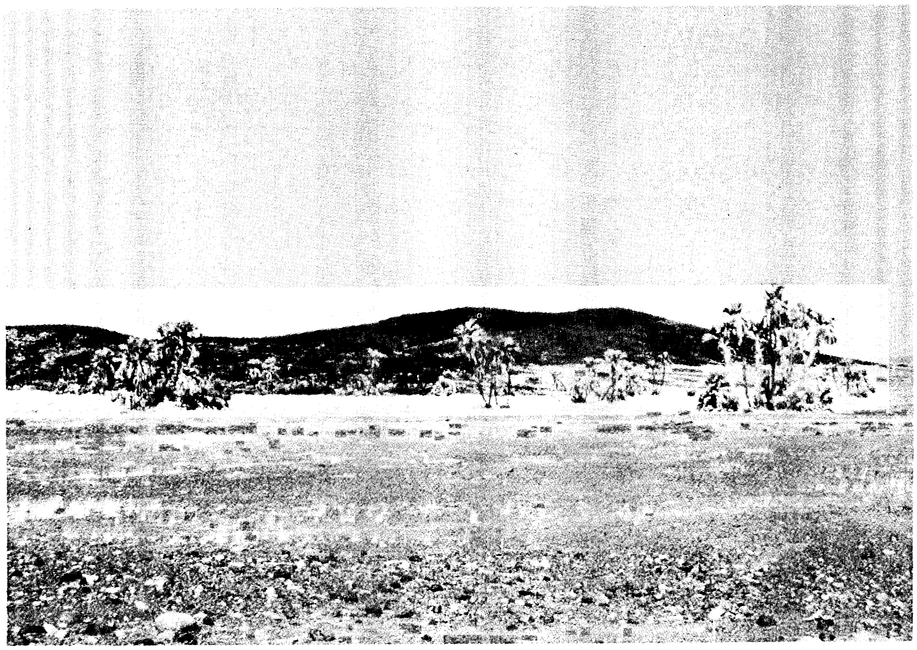
Explanation of Plate 1

Fig. 1 The scoria cone in the Suguta Valley.

Fig. 2 Ankaramite of the Aka Aiteputh Formation (82092817).
Scale bar is 0.5 mm here and after.
ol: olivine cpx: clinopyroxene

Plate 1



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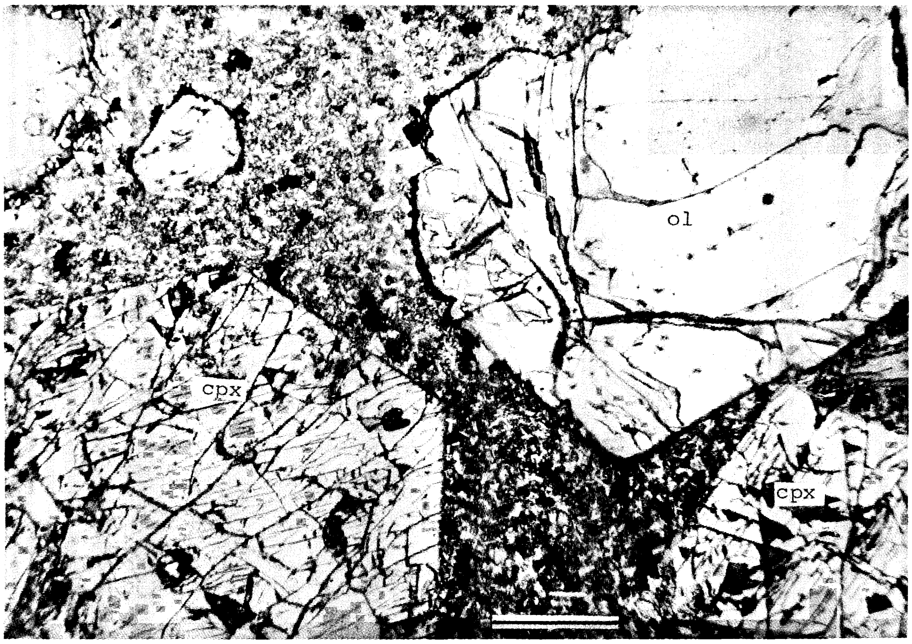

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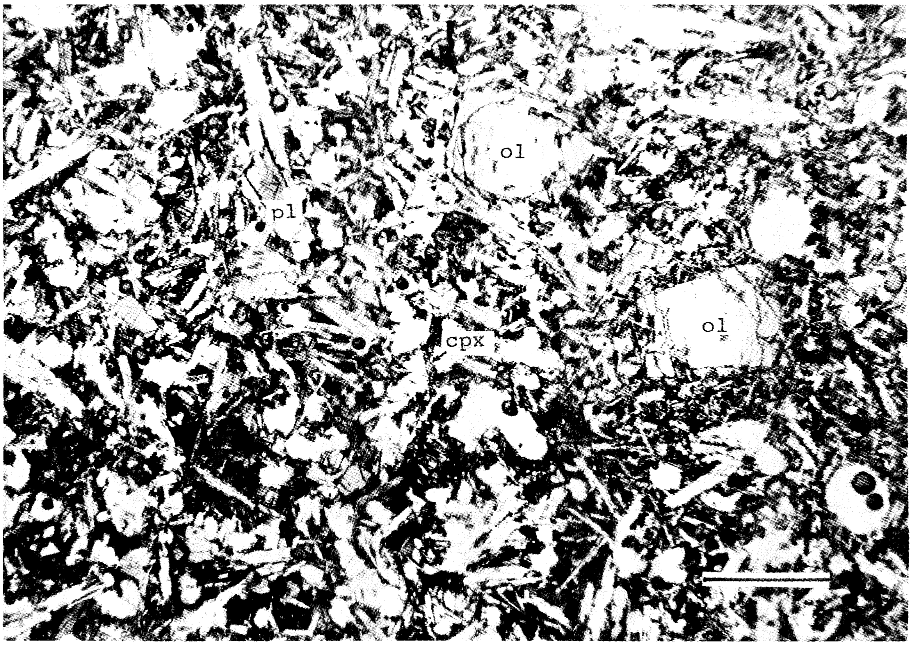
Explanation of Plate 2

Fig. 1 Alkali basalt of the scoria cone in the Suguta Valley (82083101).
pl: plagiocalse ol: olivine cpx: clinopyroxene

Fig. 2 Analcite syenite occeli in alkali basalt of the Nagubarat Formation (N-32).
a.o.: analcite syenite occelus ol: olivine cpx: clinopyroxene

Plate 2



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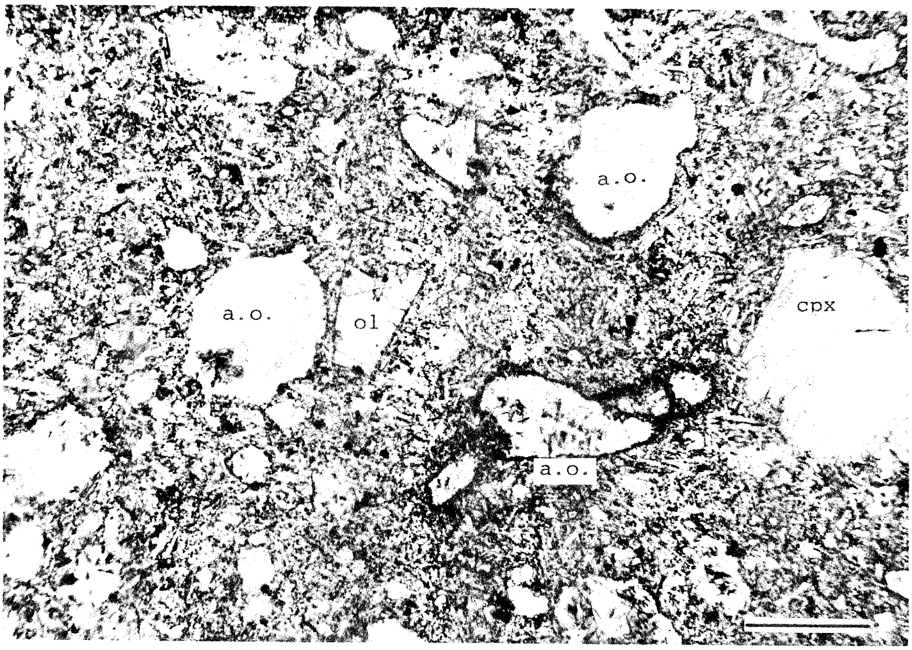

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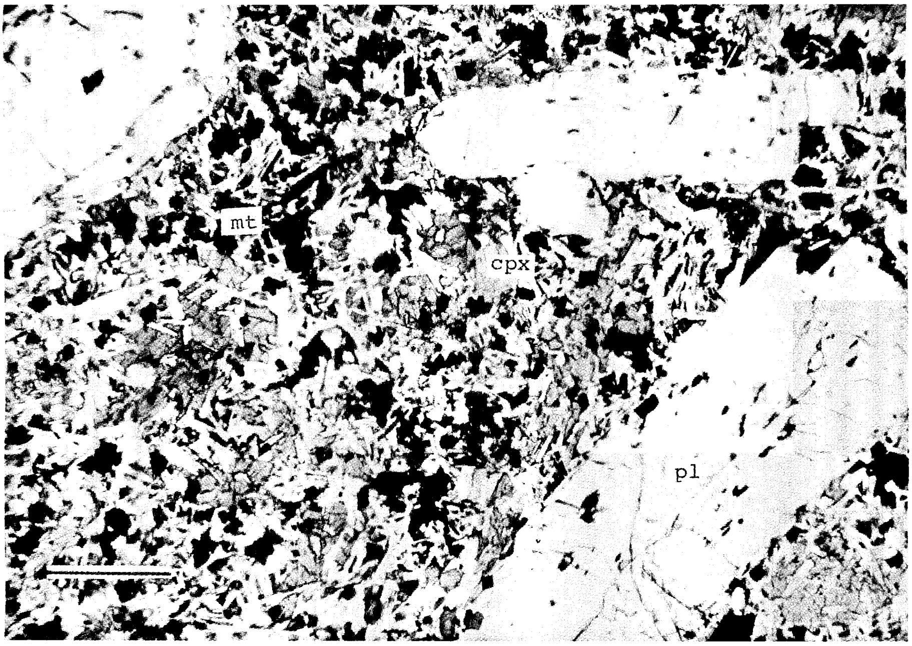
Explanation of Plate 3

Fig. 1 Hawaiite of the Kongia Formation (82083113).
mt: magnetite cpx: clinopyroxene pl: plagioclase

Fig. 2 Phonolitic trachyte of the Nachola Formation (82092505).
mt: magnetite cpx: clinopyroxene

Plate 3



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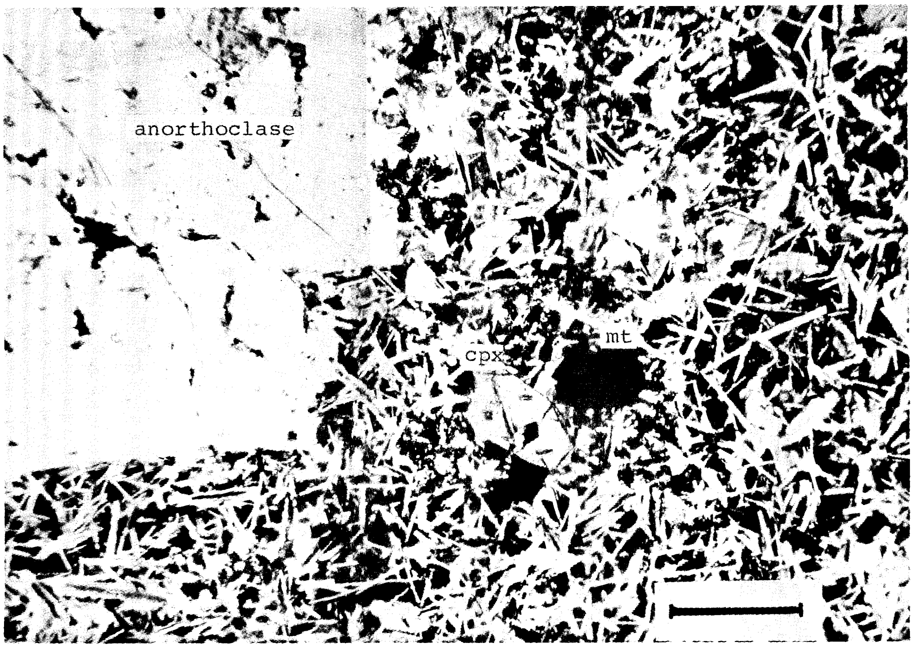

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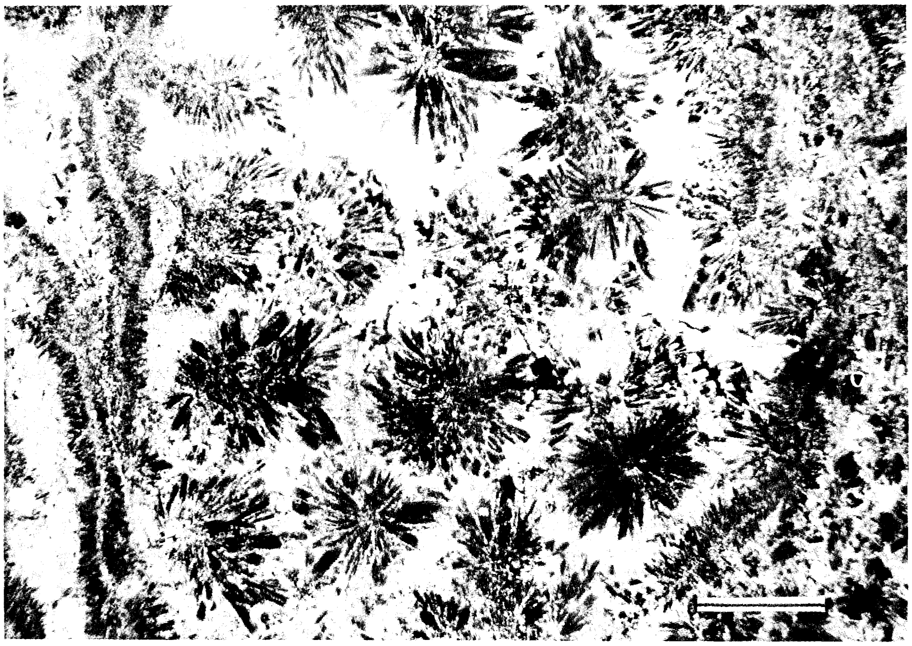
Explanation of Plate 4

Fig. 1 Spherulites in phonolitic trachyte of the Nachola Formation (82092503).

Fig. 2 Sodalite trachyte of the Aka Aiteputh Formation (82100901).
sod: sodalite

Plate 4



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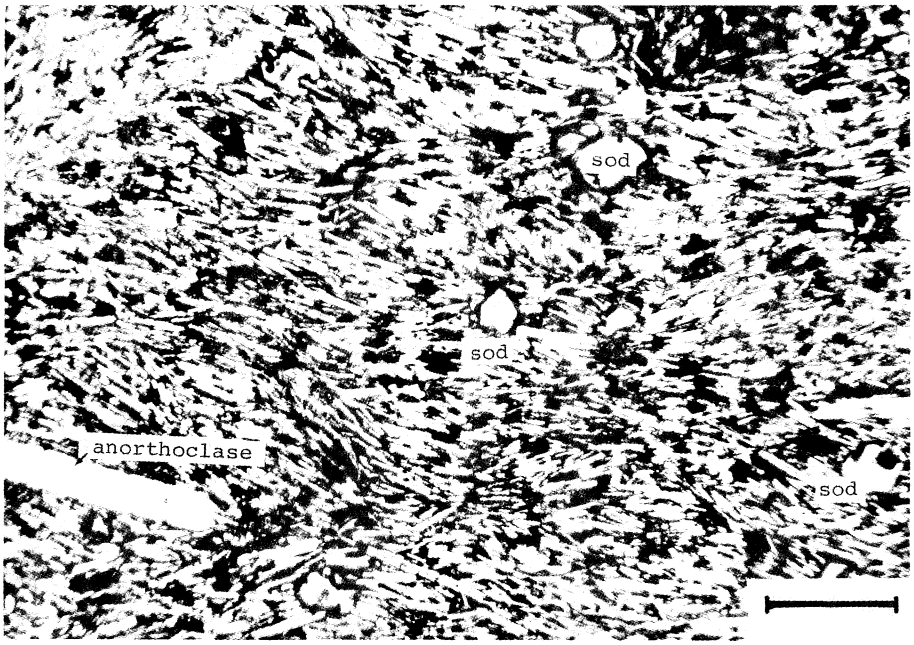

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Explanation of Plate 5

Fig. 1 Alkali rhyolite of the Tirr Tirr Formation (82100404).
ol: olivine

Plate 5